Inclusive and exclusive $b \to s l^+ l^-$ and $b \to s\gamma$ decays at BaBar

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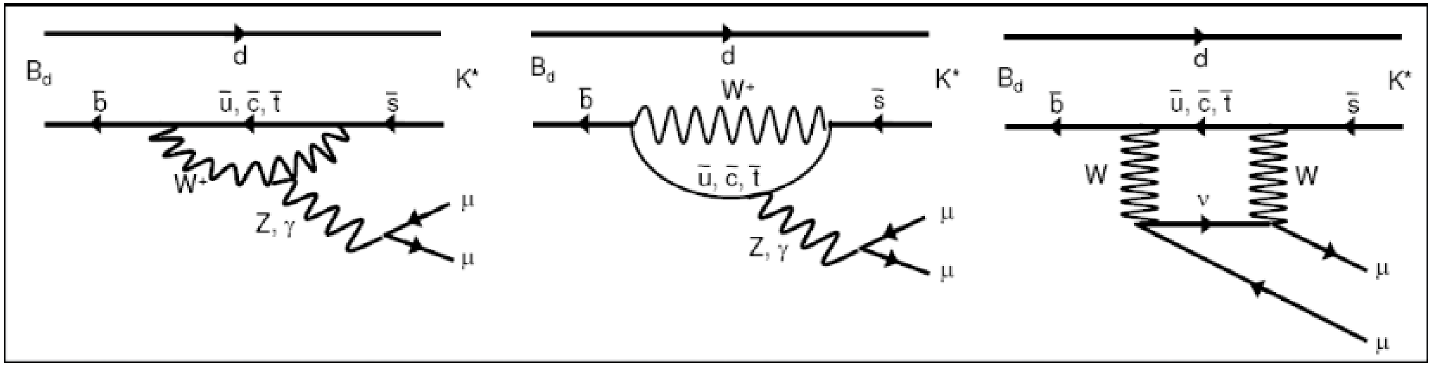
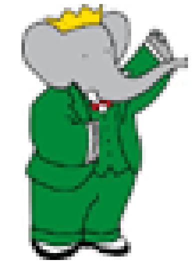
Outline

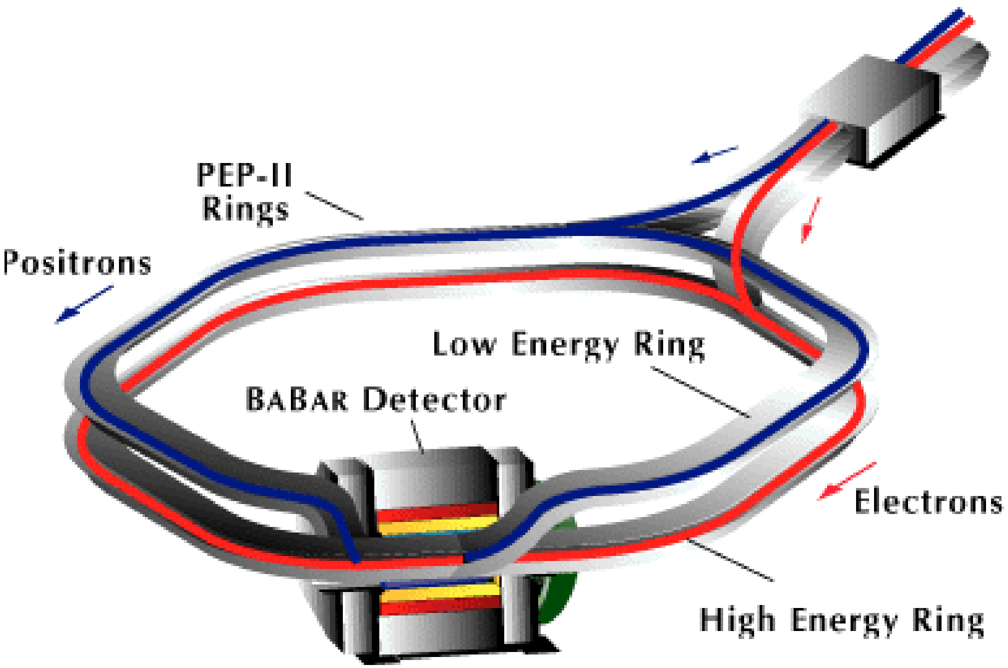
- Flavour-changing neutral current B decays are sensitive to physics beyond the Standard Model
- Various observables can be constructed to test the SM: rates, asymmetries (kinematic, isospin, CP)
  - Results can be used to constrain Wilson coefficients
- BaBar collaboration has published many such measurements, but still has a few up its sleeve. Recent results include
  - $B \rightarrow X_s\gamma$: A_{CP} & ΔA_{CP} arXiv:1406.0534 (submitted to PRD)
  - $B \rightarrow X_s l^+ l^-$: $\Delta B/\Delta q^2$ & A_{CP} PRL 112 (2014) 211802
  - $B \rightarrow K\pi\pi\gamma$: photon polarisation preliminary (to be submitted to PRD)

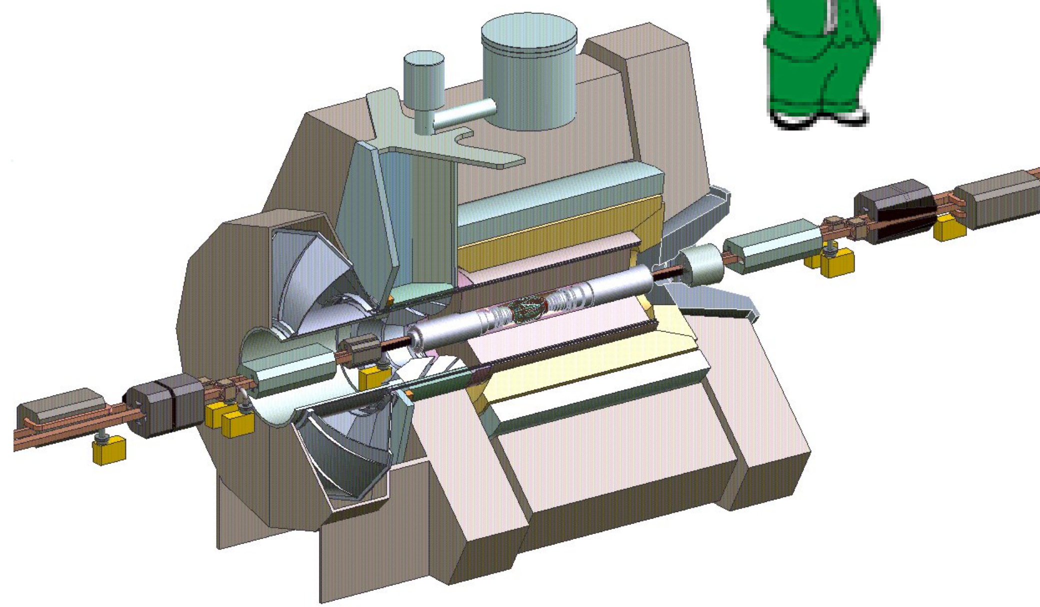


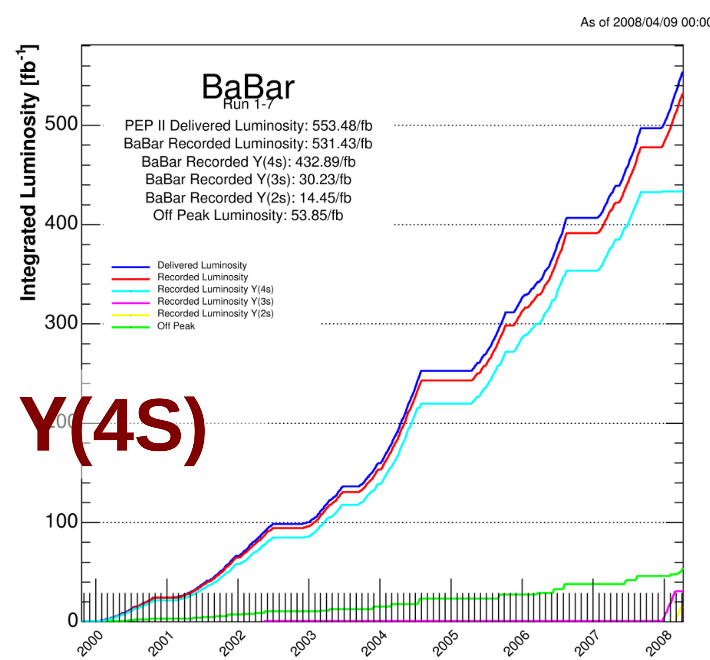
PEPII & BaBar

9.0 GeV e^- on 3.1 GeV e^+





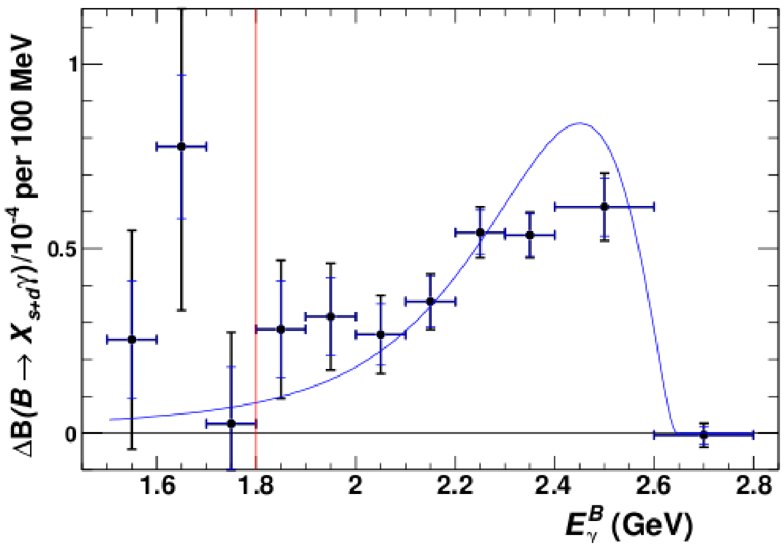




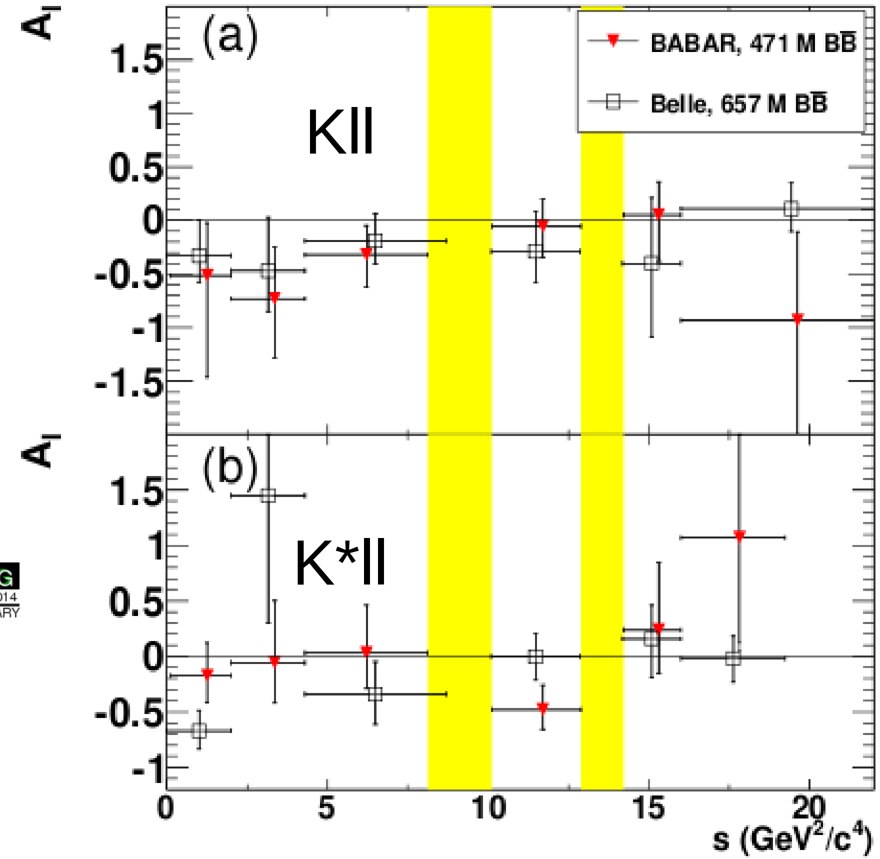
~ 433/fb on Υ(4S)

Context setting – prior results

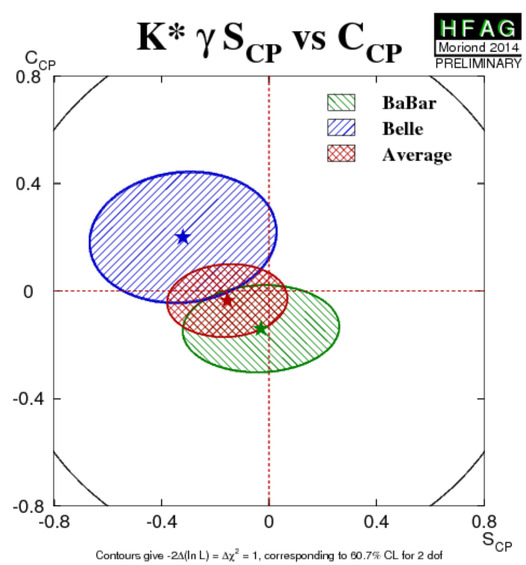
PRL 109 (2012) 191801 &
PR D86 (2012) 112008



PR D86 (2012) 032012



PRD 78 (2008) 071102



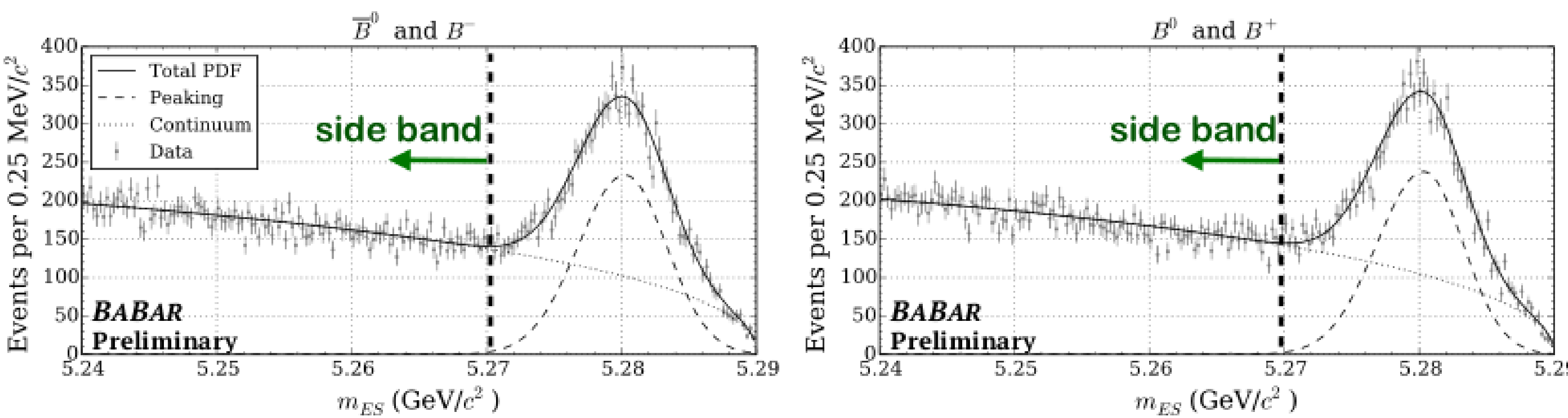
CP asymmetries in $B \to X_s\gamma$

- To study CP asymmetries in $B \to X_s\gamma$ & $B \to X_d\gamma$ separately
  - cannot use fully inclusive approach
  - instead, use “semi-inclusive” (i.e. sum of exclusive) technique
  - many modes studies; 10 B^+ & 6 B^0 decays used for final measurement (marked with ♥)
  - require
    - $0.6 < m(X_s) < 2.0$ GeV
      - corresponds ~ to B rest frame cut of $E_\gamma > 2.3$ GeV
    - $|\Delta E| < 0.15$ GeV
    - MVA to reject $q\bar{q}$ background

1 ♥	$B^+ \to K_S\pi^+\gamma$	20	$B^0 \to K_S\pi^+\pi^-\pi^+\pi^-\gamma$
2 ♥	$B^+ \to K^+\pi^0\gamma$	21	$B^0 \to K^+\pi^+\pi^-\pi^-\pi^0\gamma$
3 ♥	$B^0 \to K^+\pi^-\gamma$	22	$B^0 \to K_S\pi^+\pi^-\pi^0\pi^0\gamma$
4	$B^0 \to K_S\pi^0\gamma$	23 ♥	$B^+ \to K^+\eta\gamma$
5 ♥	$B^+ \to K^+\pi^+\pi^-\gamma$	24	$B^0 \to K_S\eta\gamma$
6 ♥	$B^+ \to K_S\pi^+\pi^0\gamma$	25	$B^+ \to K_S\eta\pi^+\gamma$
7 ♥	$B^+ \to K^+\pi^0\pi^0\gamma$	26	$B^+ \to K^+\eta\pi^0\gamma$
8	$B^0 \to K_S\pi^+\pi^-\gamma$	27 ♥	$B^0 \to K^+\eta\pi^-\gamma$
9 ♥	$B^0 \to K^+\pi^-\pi^0\gamma$	28	$B^0 \to K_S\eta\pi^0\gamma$
10	$B^0 \to K_S\pi^0\pi^0\gamma$	29	$B^+ \to K^+\eta\pi^+\pi^-\gamma$
11 ♥	$B^+ \to K_S\pi^+\pi^-\pi^+\gamma$	30	$B^+ \to K_S\eta\pi^+\pi^0\gamma$
12 ♥	$B^+ \to K^+\pi^+\pi^-\pi^0\gamma$	31	$B^0 \to K_S\eta\pi^+\pi^-\gamma$
13 ♥	$B^+ \to K_S\pi^+\pi^0\pi^0\gamma$	32	$B^0 \to K^+\eta\pi^-\pi^0\gamma$
14 ♥	$B^0 \to K^+\pi^+\pi^-\pi^-\gamma$	33 ♥	$B^+ \to K^+K^-K^+\gamma$
15	$B^0 \to K_S\pi^0\pi^+\pi^-\gamma$	34	$B^0 \to K^+K^-K_S\gamma$
16 ♥	$B^0 \to K^+\pi^-\pi^0\pi^0\gamma$	35	$B^+ \to K^+K^-K_S\pi^+\gamma$
17	$B^+ \to K^+\pi^+\pi^-\pi^+\pi^-\gamma$	36	$B^+ \to K^+K^-K^+\pi^0\gamma$
18	$B^+ \to K_S\pi^+\pi^-\pi^+\pi^0\gamma$	37 ♥	$B^0 \to K^+K^-K^+\pi^-\gamma$
19	$B^+ \to K^+\pi^+\pi^-\pi^0\pi^0\gamma$	38	$B^0 \to K^+K^-K_S\pi^0\gamma$

CP asymmetries in B → $X_s\gamma$

- Raw asymmetry (from fitted yields) corrected for
  - Detection asymmetry, taken from sidebands
    - (−1.4 ± 0.7)%
  - Possible asymmetry from peaking backgrounds



arXiv:1406.0534

CP asymmetries in $B \to X_s\gamma$

- Results

$$A_{CP}(B^+ \to X_s^+\gamma) = (+4.23 \pm 2.93 \pm 0.95)\%$$

$$A_{CP}(B^0 \to X_s^0\gamma) = (-0.74 \pm 2.57 \pm 1.10)\%$$

→ Average

$$A_{CP}(B \to X_s\gamma) = (+1.7 \pm 1.9 \pm 1.0)\%$$

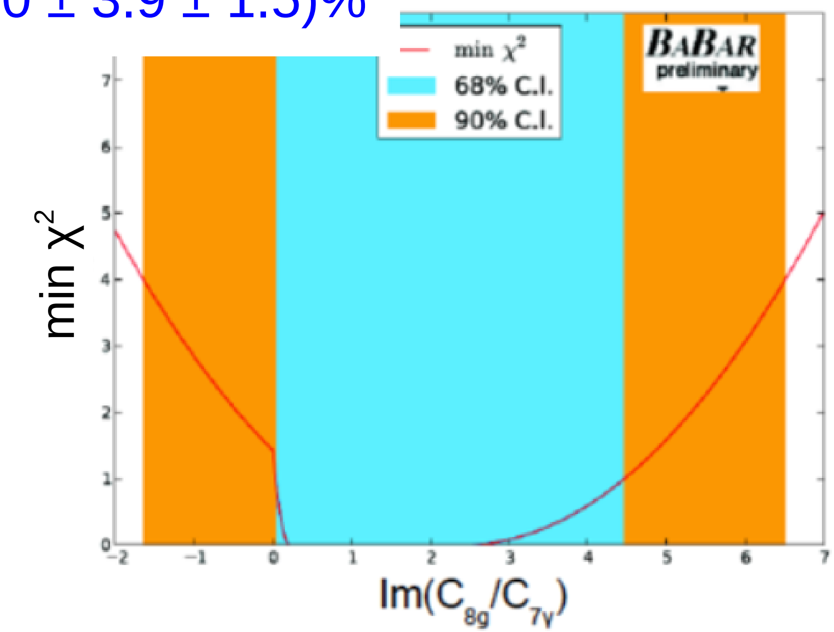
→ Difference

$$\Delta A_{CP}(B \to X_s\gamma) = (+5.0 \pm 3.9 \pm 1.5)\%$$

→ Constraint on Wilson coefficient C_8

(PRL 106 (2011) 141801)

- consistent with SM
  - i.e. $\Delta A_{CP} \sim 0$; $\text{Im}(C_8) \sim 0$



PRL 112 (2014) 211802

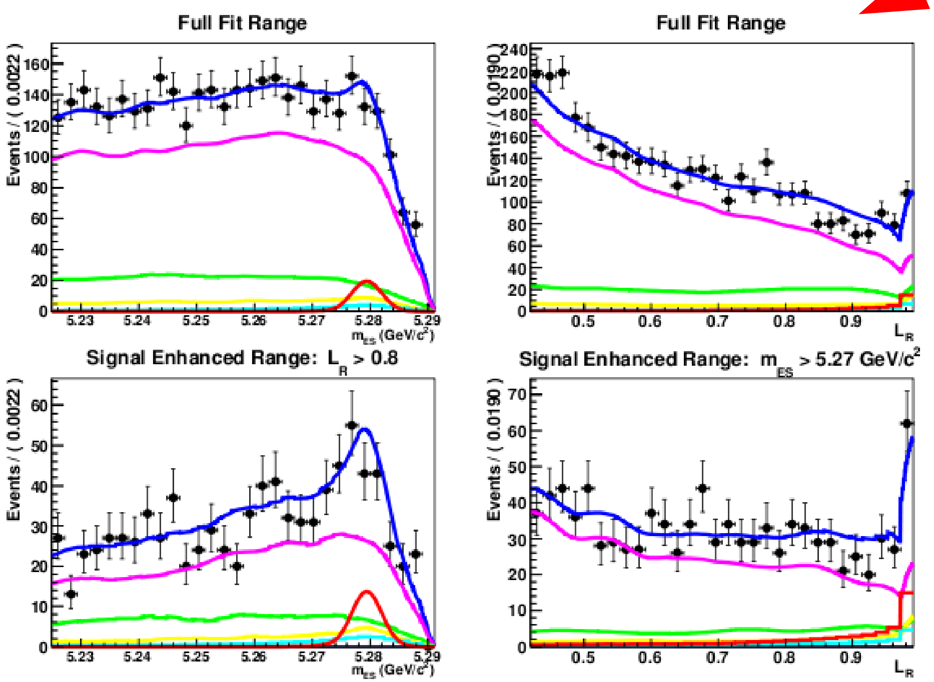
Differential branching fraction and CP asymmetries in $B \to X_s l^+l^-$

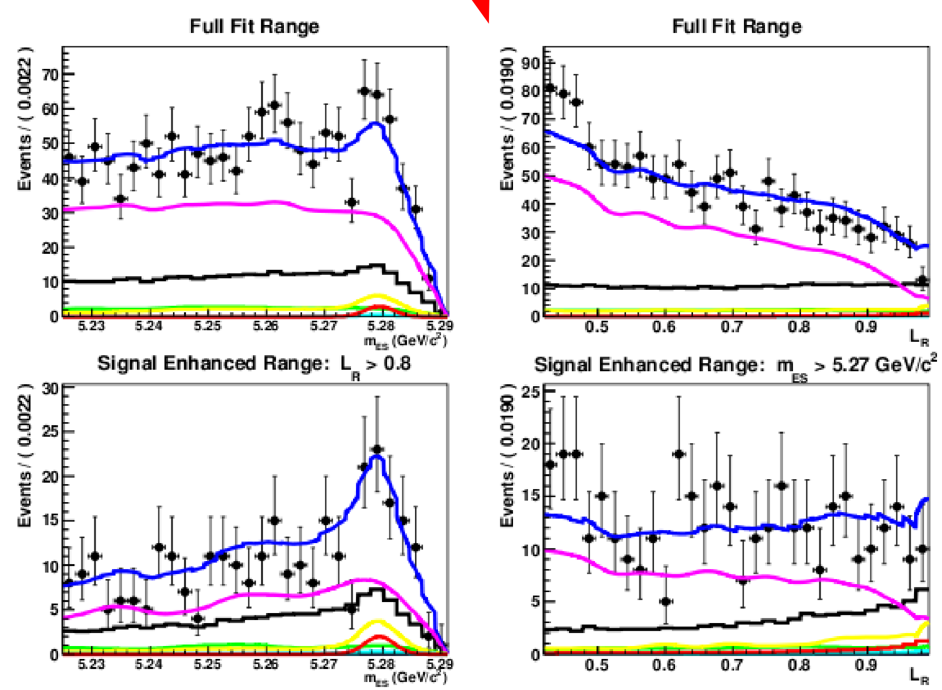
- Similar "semi-inclusive" approach, but smaller set of modes used (since fewer events)
  - $X_s = \{K^+, K^+\pi^0, K^+\pi^-, K^+\pi^-\pi^0, K^+\pi^-\pi^+, K_S, K_S\pi^0, K_S\pi^+, K_S\pi^+\pi^0, K_s\pi^+\pi^-\}$; $m(X_s) < 1.8$ GeV
    - expected to account for ~70% of the rate (after correcting for $K_s \leftrightarrow K_L$ and $K_s \to \pi^0\pi^0$)
    - only self-tagging modes used for A_{CP} measurement
  - $l^+l^- = \{e^+e^-, \mu^+\mu^-\}$; fit in bins of $m^2(l^+l^-) = q^2$
  - require -0.1 (-0.05) $< \Delta E < 0.05$ GeV for $l^+l^- = e^+e^-$ ($\mu^+\mu^-$)

PRL 112 (2014) 211802

Differential branching fraction and CP asymmetries in $B \rightarrow X_s l^+l^-$

- Simultaneous fit to m_{ES} and likelihood ratio variable L
- Example plots for lowest q^2 bin: e^+e^- & $\mu^+\mu^-$



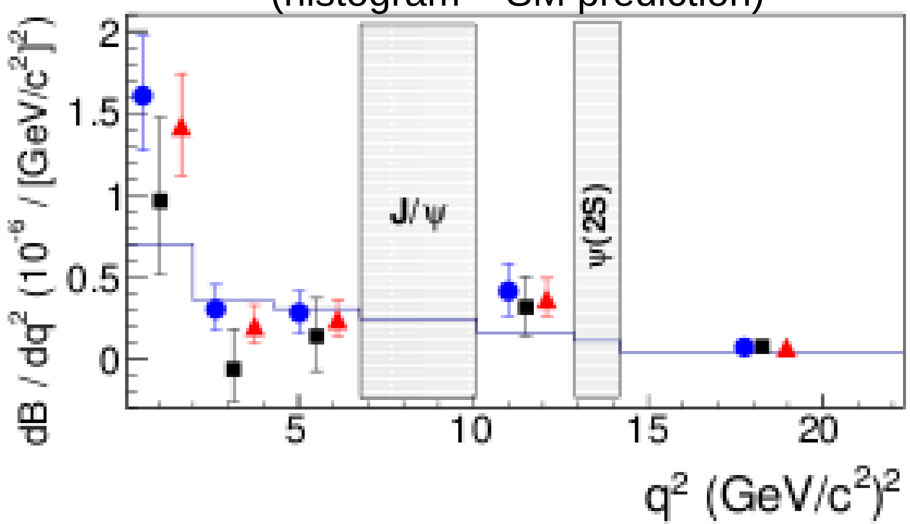


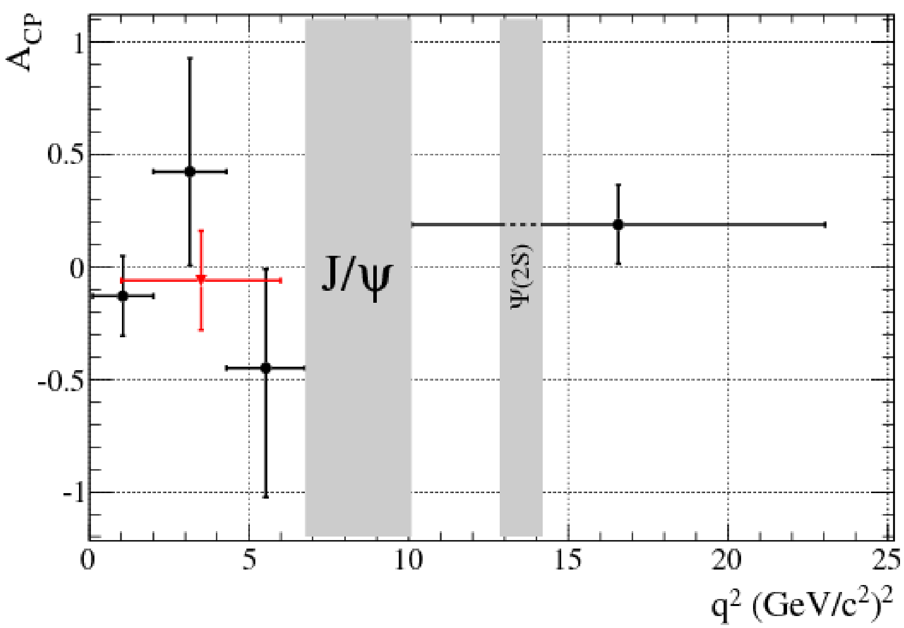
PRL 112 (2014) 211802

Differential branching fraction and CP asymmetries in $B \to X_s l^+l^-$

- Results

l^+l^- = e^+e^-, $\mu^+\mu^-$, combined
(histogram = SM prediction)





Differential branching fraction consistent with expectation.
Integrated value ($q^2 > 0.1\mathrm{GeV}^2$)

$$\mathcal{B}(B \to X_s l^+l^-) = (6.73\ ^{+0.70}_{-0.64}\ ^{+0.34}_{-0.25} \pm 0.50) \times 10^{-6}$$

(stat) (syst) (model)

CP asymmetry consistent with zero.
Integrated value ($q^2 > 0.1\mathrm{GeV}^2$)

$$A_{CP} = 0.04 \pm 0.11 \pm 0.01$$

preliminary

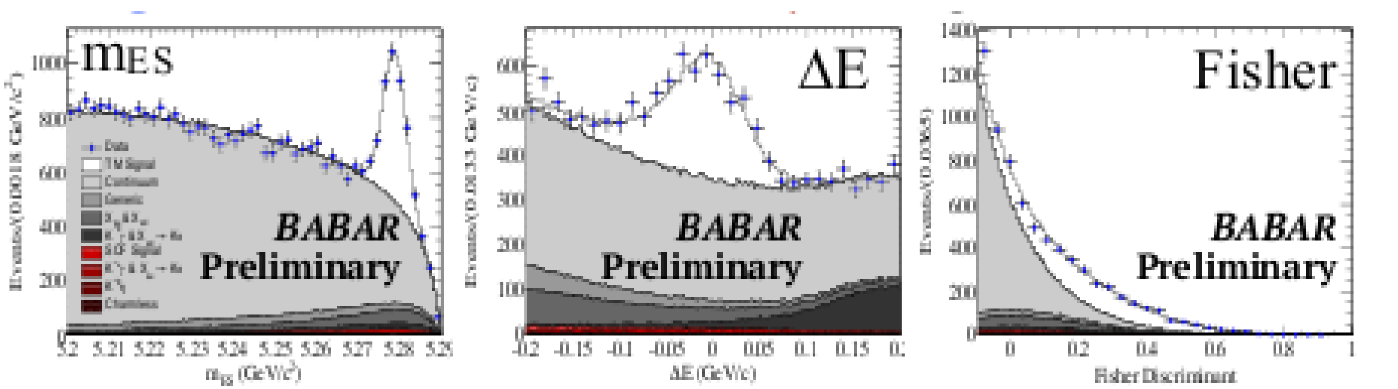
Photon polarisation in $B \to K\pi\pi\gamma$

- Photon polarisation in $b \to s\gamma$ transitions excellent probe for physics beyond SM
- Powerful method from time-dependent asymmetries of B^0 (also B_s^0) decays
  - if photon 100% polarised (~ as in SM), B and $\overline{B}$ give different final states $\to$ no interference: S = 0
  - if less polarised, interference term appears: S ~ sin(2ψ) sin(Φ)
    - ψ ~ polarisation; Φ ~ CP violation (PRL 79 (1997) 185, PRD71 (2005) 076003)
- Problem to accumulate enough statistics for a sensitive measurement
  - results from both BaBar and Belle on $B^0 \to (K_S\pi^0)_{K^*}\gamma$
  - desirable to add more final states, e.g. $B^0 \to K_S\rho^0\gamma$

preliminary

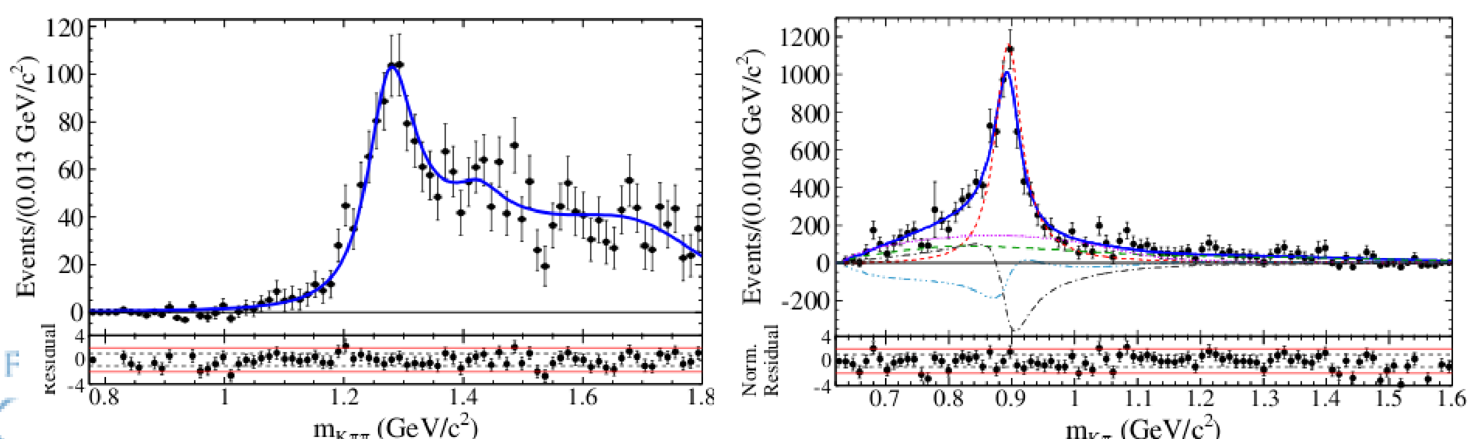
Photon polarisation in B→Kππγ

- Due to width of ρ meson, necessary to determine dilution factor
  - due to contributions from flavour-specific B→K*πγ amplitude
  - $D_{K\rho\gamma} = S_{K\rho\gamma}/S_{K\pi\pi\gamma} = 0.549\ ^{+0.096}_{-0.094}$ (obtained from $B^+\rightarrow K^+\pi^+\pi^-\gamma$ decays)



separate signal from background

determine *D* from m(Kππ) and m(Kπ)



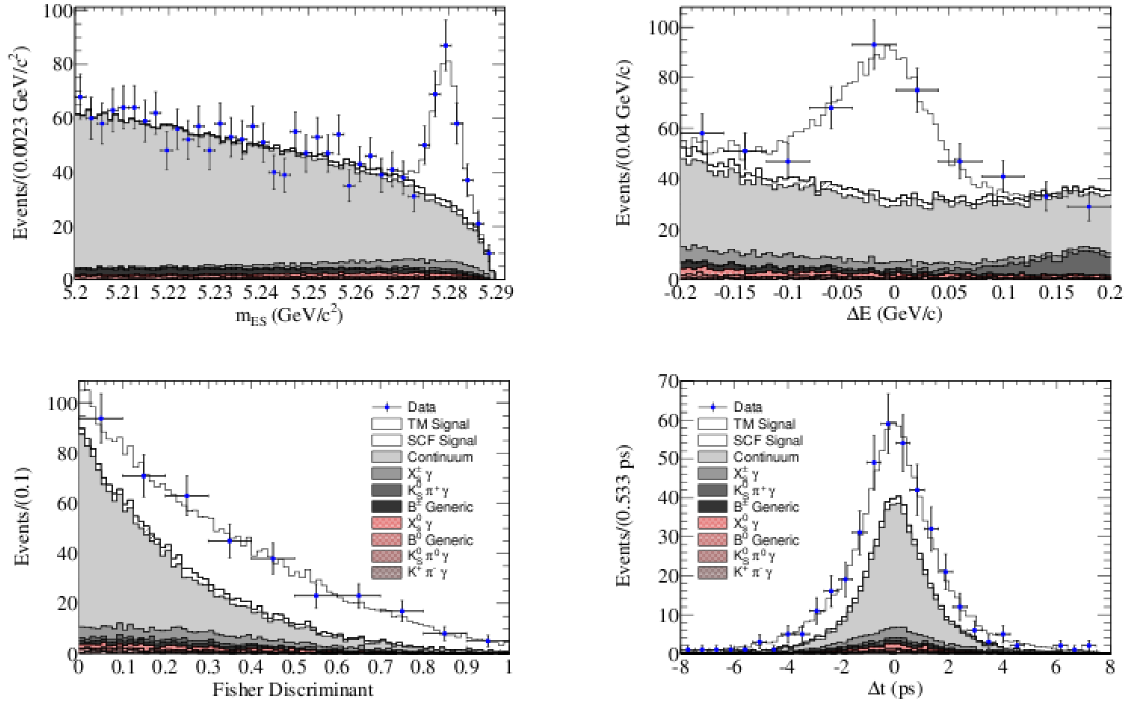
Aside: Kππ hadronic system

- Increasing number of channels analysed where understanding of the Kππ hadronic system is important
  - B→(Kππ) π BaBar PR D81 (2010) 052009
  - B→(Kππ) J/ψ Belle PR D83 (2011) 032005
  - B→(Kππ) D LHCb LHCb-CONF-2012-021
  - B→(Kππ) γ BaBar preliminary
  - B→(Kππ) γ LHCb PRL 112 (2014) 161801
  - B→(Kππ) μμ LHCb 1408.1137
- Possible benefit from developing common tools to handle hadronic system?
  - (same also true for the Kπ system)

preliminary

Photon polarisation in B→Kππγ

- Fit to $B^0 \to K_S \pi^+ \pi^- \gamma$ sample



$$\mathcal{S}_{K_S^0\pi^+\pi^-\gamma} = 0.137 \pm 0.249(\text{stat.})^{+0.042}_{-0.033}(\text{syst.})$$
$$\mathcal{C}_{K_S^0\pi^+\pi^-\gamma} = -0.390 \pm 0.204(\text{stat.})^{+0.045}_{-0.050}(\text{syst.})$$

+

$$\mathcal{D}_{K_S^0\rho\gamma} = 0.549^{+0.096}_{-0.094}$$

↳

$$\mathcal{S}_{K_S^0\rho\gamma} = \frac{\mathcal{S}_{K_S^0\pi^+\pi^-\gamma}}{\mathcal{D}_{K_S^0\rho\gamma}} = 0.249 \pm 0.455^{+0.076}_{-0.060}$$

Summary

- BaBar continues to produce important results searching for new physics in FCNCs
  - several novel approaches investigated
- All results consistent with SM
- All statistically limited
  - expect that this work will be pursued by future experiments


BACKUP

PRL 112 (2014) 211802

Differential branching fraction and CP asymmetries in $B \to X_s l^+ l^-$

- Results

Bin	Range	$B \to X_s e^+ e^-$	$B \to X_s \mu^+ \mu^-$	$B \to X_s \ell^+ \ell^-$	$A_{CP\,B\to X_s \ell^+\ell^-}$
q_0^2	$1.0 < q^2 < 6.0$	$1.93^{+0.47\,+0.21}_{-0.45\,-0.16} \pm 0.18\ (1.71)$	$0.66^{+0.82\,+0.30}_{-0.76\,-0.24} \pm 0.07\ (1.78)$	$1.60^{+0.41\,+0.17}_{-0.39\,-0.13} \pm 0.18$	$-0.06 \pm 0.22 \pm 0.01$
q_1^2	$0.1 < q^2 < 2.0$	$3.05^{+0.52\,+0.29}_{-0.49\,-0.21} \pm 0.35\ (1.96)$	$1.83^{+0.90\,+0.30}_{-0.80\,-0.24} \pm 0.20\ (2.02)$	$2.70^{+0.45\,+0.21}_{-0.42\,-0.16} \pm 0.35$	$-0.13 \pm 0.18 \pm 0.01$
q_2^2	$2.0 < q^2 < 4.3$	$0.69^{+0.31\,+0.11}_{-0.28\,-0.07} \pm 0.07\ (1.73)$	$-0.15^{+0.50\,+0.26}_{-0.43\,-0.14} \pm 0.01\ (1.80)$	$0.46^{+0.26\,+0.10}_{-0.23\,-0.06} \pm 0.07$	$0.42\ ^{+0.50}_{-0.42} \pm 0.01$
q_3^2	$4.3 < q^2 < 6.8$	$0.69^{+0.31\,+0.13}_{-0.29\,-0.10} \pm 0.05\ (1.53)$	$0.34^{+0.54\,+0.19}_{-0.50\,-0.15} \pm 0.03\ (1.59)$	$0.60^{+0.27\,+0.10}_{-0.25\,-0.08} \pm 0.05$	$-0.45^{+0.44}_{-0.57} \pm 0.01$
q_4^2	$10.1 < q^2 < 12.9$	$1.14^{+0.42\,+0.22}_{-0.40\,-0.10} \pm 0.04\ (1.16)$	$0.87^{+0.51\,+0.11}_{-0.47\,-0.08} \pm 0.03\ (1.18)$	$1.02^{+0.32\,+0.10}_{-0.30\,-0.07} \pm 0.04$	
q_5^2	$14.2 < q^2$	$0.56^{+0.19\,+0.03}_{-0.18\,-0.03} \pm 0.00\ (1.02)$	$0.60^{+0.31\,+0.05}_{-0.29\,-0.04} \pm 0.00\ (1.02)$	$0.57^{+0.16\,+0.03}_{-0.15\,-0.02} \pm 0.00$	
q_{45}^2	$q_4^2 \cup q_5^2$	—	—	—	$0.19\ ^{+0.18}_{-0.17} \pm 0.01$
$m_{X_s,1}$	$0.4 < m_{X_s} < 0.6$	$0.69^{+0.18\,+0.04}_{-0.17\,-0.03} \pm 0.00\ (1.00)$	$0.74^{+0.25\,+0.04}_{-0.23\,-0.04} \pm 0.00\ (1.00)$	$0.71^{+0.15\,+0.03}_{-0.14\,-0.03} \pm 0.00$	
$m_{X_s,2}$	$0.6 < m_{X_s} < 1.0$	$1.20^{+0.34\,+0.10}_{-0.33\,-0.07} \pm 0.00\ (1.00)$	$0.76^{+0.44\,+0.08}_{-0.40\,-0.07} \pm 0.00\ (1.00)$	$1.02^{+0.27\,+0.06}_{-0.25\,-0.05} \pm 0.00$	
$m_{X_s,3}$	$1.0 < m_{X_s} < 1.4$	$1.60^{+0.72\,+0.27}_{-0.69\,-0.19} \pm 0.05\ (1.18)$	$0.65^{+1.16\,+0.27}_{-1.08\,-0.25} \pm 0.02\ (1.18)$	$1.32^{+0.61\,+0.19}_{-0.58\,-0.15} \pm 0.05$	
$m_{X_s,4}$	$1.4 < m_{X_s} < 1.8$	$1.88^{+0.76\,+0.71}_{-0.73\,-0.47} \pm 0.12\ (1.91)$	$0.19^{+1.35\,+0.70}_{-1.25\,-0.50} \pm 0.10\ (1.91)$	$1.36^{+0.67\,+0.50}_{-0.63\,-0.34} \pm 0.12$	
Total	$0.1 < q^2$	$7.69^{+0.82\,+0.50}_{-0.77\,-0.33} \pm 0.50$	$4.41^{+1.31\,+0.57}_{-1.17\,-0.42} \pm 0.27$	$6.73^{+0.70\,+0.34}_{-0.64\,-0.25} \pm 0.50$	$0.04 \pm 0.11 \pm 0.01$

preliminary

Photon polarisation in B→Kππγ

Mode	$\mathcal{B}(B^+\to \text{Mode})\times \mathcal{B}(K_{\text{res}}\to K^+\pi^+\pi^-)\times 10^{-6}$	$\mathcal{B}(B^+\to \text{Mode})\times 10^{-6}$	PDG values $(\times 10^{-6})$
Inclusive $B^+\to K^+\pi^+\pi^-\gamma$	$\cdots$	$27.2\pm 1.0^{+1.1}_{-1.3}$	27.6 ± 2.2
$K_1(1270)^+\gamma$	$14.5^{+2.0+1.1}_{-1.3-1.2}$	$44.0^{+6.0+3.5}_{-4.0-3.7}\pm 4.6$	43 ± 13
$K_1(1400)^+\gamma$	$4.1^{+1.9+1.3}_{-1.2-0.8}$	$9.7^{+4.6+3.1}_{-2.9-1.8}\pm 0.6$	<15 CL$=90\%$
$K^*(1410)^+\gamma$	$9.7^{+2.1+2.4}_{-1.9-0.7}$	$23.8^{+5.2+5.9}_{-4.6-1.4}\pm 2.4$	$\emptyset$
$K_2^*(1430)^+\gamma$	$1.5^{+1.2+0.9}_{-1.0-1.4}$	$10.4^{+8.7+6.3}_{-7.0-9.9}\pm 0.5$	14 ± 4
$K^*(1680)^+\gamma$	$17.0^{+1.7+3.5}_{-1.4-3.0}$	$71.7^{+7.2+15}_{-5.7-13}\pm 5.8$	<1900 CL$=90\%$

Mode	$\mathcal{B}(B^+\to \text{Mode})\times \mathcal{B}(R\to hh)\times 10^{-6}$	$\mathcal{B}(B^+\to \text{Mode})\times 10^{-6}$	PDG values $(\times 10^{-6})$
Inclusive $B^+\to K^+\pi^+\pi^-\gamma$	$\cdots$	$27.2\pm 1.0^{+1.1}_{-1.3}$	27.6 ± 2.2
$K^{*0}(892)\pi^+\gamma$	$17.3\pm 0.9^{+1.2}_{-1.1}$	$26.0^{+1.4}_{-1.3}\pm 1.8$	20^{+7}_{-6}
$K^+\rho(770)^0\gamma$	$9.1^{+0.8}_{-0.7}\pm 1.3$	$9.2^{+0.8}_{-0.7}\pm 1.3\pm 0.02$	<20 CL$=90\%$
$(K\pi)^{*0}_0\pi^+\gamma$	$11.3\pm 1.5^{+2.0}_{-2.6}$	$\cdots$	$\emptyset$
$(K\pi)^0_0\pi^+\gamma$ (NR)	$\cdots$	$10.8^{+1.4+1.9}_{-1.5-2.5}$	<9.2 CL$=90\%$
$K_0^*(1430)^0\pi^+\gamma$	$0.51\pm 0.07^{+0.09}_{-0.12}$	$0.82\pm 0.11^{+0.15}_{-0.19}\pm 0.08$	$\emptyset$